A Peculiar Family of Jupiter Trojans: the Eurybates*

F. De Luise[1,2], E. Dotto[1], S. Fornasier[3,4],
M.A. Barucci[3], N. Pinilla-Alonso[5,6], D. Perna[1,3,7], and F. Marzari[8]

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[1] INAF-Osservatorio Astronomico di Roma, Via Frascati 33, 00040 Monteporzio Catone (Roma), Italy;

[2] INAF-Osservatorio Astronomico di Collurania-Teramo, Via Mentore Maggini, s.n.c., 64100 Teramo (TE), Italy;

[3] LESIA, Paris Observatory, 5 Place Jules Janssen, 92195 Meudon Cedex, France;

[4] University of Paris VII "Denis Diderot", 4 rue Elsa Morante, 75013 Paris, France;

[5] Fundación Galileo Galilei & Telescopio Nazionale Galileo, PO Box 565, 38700 S/C de La Palma, Tenerife, Spain;

[6] Oak Ridge Associated Universities (ORAU) - NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000;

[7] University of Rome "Tor Vergata", Via della Ricerca Scientifica 1, 00133 Roma, Italy;

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[8] Dipartimento di Fisica - University of Padova, Via Marzolo 8, 35131 Padova, Italy.

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Send correspondence to:

De Luise Fiore

INAF-Osservatorio Astronomico di Collurania-Teramo

Via Mentore Maggini, s.n.c.

I-64100 Teramo

Italy

e-mail: deluise@oa-teramo.inaf.it

phone: +39-0861-439712

fax: +39-0861-439740;

Abstract

The Eurybates family is a compact core inside the Menelaus clan, located in the L_4 swarm of Jupiter Trojans. Fornasier et al. (2007) found that this family exhibits a peculiar abundance of spectrally flat objects, similar to Chiron-like Centaurs and C-type main belt asteroids. On the basis of the visible spectra available in literature, Eurybates family's members seemed to be good candidates for having on their surfaces water/water ice or aqueous altered materials.
To improve our knowledge of the surface composition of this peculiar family, we carried out an observational campaign at the Telescopio Nazionale Galileo (TNG), obtaining near-infrared spectra of 7 members. Our data show a surprisingly absence of any spectral feature referable to the presence of water, ices or aqueous altered materials on the surface of the observed objects. Models of the surface composition are attempted, evidencing that amorphous carbon seems to dominate the surface composition of the observed bodies and some amount of silicates (olivine) could be present.

Keywords: Jupiter Trojans – Dynamical families – Spectroscopy – Near-infrared

1 Introduction

Jupiter Trojans (JTs) are small bodies of the Solar System located in the Jupiter's Lagrangian points L_4 and L_5. Their origin is not yet well understood and it is still matter of debate. Several mechanisms were proposed to model their origin (Marzari & Scholl, 1998a,b, 2000, 2007; Marzari et al., 2002; Morbidelli et al., 2005), and it is widely accepted that they formed in the outer Solar System, in regions rich in frozen volatiles. The JT population is supposed to have undergone a significant collisional evolution, and to be at least as collisionally evolved as main belt asteroids. The discovery of dynamical families in both L_4 and L_5 clouds supports this hypothesis (e.g. Milani, 1993; Milani & Knežević, 1994; Beaugé & Roig, 2001; Dell'Oro et al., 1998).

Physical properties of JTs are poorly known. The presently available spectroscopic data set is largely unsatisfactory, covering only about 10% of the entire JT population. To improve our knowledge of the nature of these bodies, in the last years several surveys have been carried out, both in visible and infrared wavelengths (Dotto et al., 2008, and reference therein). Although JTs formed at large heliocentric distances, the data so far acquired have shown a lack of any evidence of ices on their surfaces. Emery & Brown (2003, 2004) analysed the content of water ice and hydrated materials on the surface of 17 JTs, obtaining upper limits of a few% for water ice and of 30% for hydrated materials. More recently, Yang & Jewitt (2007) suggested that water ice can occupy no more than 10% of the total surface of (4709)

Ennomos. JTs belonging to dynamical families do not exibit any spectral feature related to the presence of ices on their surface (Dotto et al., 2006).

The data so far available in the literature put in evidence a great homogeneity in the whole population: all of the known JTs are low albedo bodies belonging to the primitive C, P or D classes. The same uniformity is also found in JTs belonging to dynamical families (Fornasier et al., 2004, 2007; Dotto et al., 2006). However, some differences between the L_4 and L_5 swarms are evident: as discussed by Fornasier et al. (2007), the majority of L_5 JTs are D-types, while an higher presence of C and P types is observed among the L_4 objects.

A peculiar case is given by the Eurybates dynamical family, in the L_4 swarm. This family is a strong cluster inside the Menelaus clan (Roig et al., 2008), which survives also at a very low relative velocity cut-off, as defined by Beaugé and Roig (2001). The family population, up to date, is composed by 28 members at a cut-off of 70 m/s, 22 of them surviving also at 40 m/s. On the basis of the dynamical properties, it is still not possible to understand if the Eurybates members constitute a distinct family that lies in the same space of proper elements of Menelaus or, as suggested by Roig et al. (2008), they formed by a secondary break-up of a former Menelaus member.

Although the Eurybates family is clustered, in the space of proper elements, in a small portion of the region occupied by the Menelaus clan, its members show spectral properties quite different from those of Menelaus: as shown by Roig et al. (2008) the Menelaus clan evidences a larger diversity of taxonomic classes including C, P, and D-type objects in agreement with

the whole JT population, while the Eurybates members are characterized by almost flat visible spectra (see e.g. Fig. 12 in Roig et al., 2008), with spectral slopes strongly clustered around 2 $\%/10^3$ Å, and spectral behaviors similar to those of C–type main belt asteroids and/or Chiron-like Centaurs (Fornasier et al., 2007).

The Eurybates family assumes a great importance in the study of JTs because such a peculiar clustering of spectrally flat objects strongly affects the color-size-orbital parameter distributions of the whole JT population investigated up to now. Fornasier et al. (2007) noted how this family fills the distribution of spectrally neutral JTs at low inclination and appears to be the major responsible of a color-inclination trend (bluer bodies concentrated at lower inclination) of the whole JT population. In the same paper, the Eurybates family appears also to be the major cause of the abundance of C- and P-types among the L_4 objects, which would imply a more heterogeneous composition of this swarm than the L_5 one. Moreover, the Eurybates family strongly contributes to the population of L_4 small JTs (with a $D<40$ km) having low spectral slopes.

The observations made by Fornasier et al. (2007) showed the presence of a drop-off of reflectance shortward of 0.52 μm in the visible spectra of four Eurybates members (18060, 24380, 24420 and 39285). This behavior is detected on the spectra of many main belt C-type asteroids (Vilas, 1994; 1995), and it is often associated to other spectral features due to aqueous alteration products. Since no other absorption features were found on the visible spectra of Eurybates members, we still do not have a final proof that aqueous

alteration processes occurred on the surface of these bodies. Nevertheless, the presence of the ultraviolet drop-off could suggest that subsurface water or water ice could have been present on Eurybates members at a certain moment of their life, in order to cause aqueous alteration on their surfaces. They are therefore good candidates to preserve still detectable spectral signatures of water/water ice or aqueous altered materials.

2 Observations and Data Analysis

To constrain the surface composition of Eurybates family's members, we performed an observational spectroscopic campaign in the near infrared (NIR) wavelength range.

The observations were carried out at the 3.6 m Telescopio Nazionale Galileo (TNG) at Roque de Los Muchachos in La Palma (Canary Islands, Spain) in 2006 and 2007 (AOT14-TAC41 and AOT15-TAC69, respectively). The targets were selected using the list defined by Beaugé and Roig (2001) and the P.E.Tr.A. project[1]. We observed 7 objects already investigated in visible range by Fornasier et al. (2007). With the exception of 163135, all of our targets survive at a velocity cut-off of 40 m/s. The observational circumstances are summarized in Tab. 1.

We used the Near Infrared Camera Spectrometer (NICS), a multimode instrument based on a HgCdTe Hawaii 1024x1024 array, with a field of view of 4.2 x 4.2 arcmin, coupled with the AMICI prism. Our observations were carried out in low resolution spectroscopic mode, covering the 0.9–2.4 μm

[1]http://www.daf.on.br/froig/petra/

spectral range, using a 5 arcsec wide slit, oriented in the object moving direction. The total exposure time was divided into several sub-spectra of 120 s each, to reduce the noise contribution typical of sky at NIR wavelengths. The observations were done by nodding the object along the slit by 30 arcsec between two positions A and B. Flat-fields were also acquired at the beginning of each night.

Data were reduced using the standard procedure (e.g. Dotto et al., 2006) with MIDAS and the IDL software packages. The two averaged A and B images were subtracted from each other. The $A-B$ and $B-A$ images were flat-fielded, corrected for spatial and spectral distortion and finally combined with a 30-arcsec offset. The spectra were hence extracted from the resulting combined images. Wavelength calibration was obtained using a look-up table, available on the TNG website, which is based on the theoretical dispersion predicted by ray-tracing and adjusted to best fit the observed spectra of calibration sources. The telluric absorption correction and the removal of the solar contribution were obtained by dividing the spectrum of each object by the spectrum of the solar analog star closest in time and airmass to the target (see Tab. 1). The resulting spectra were smoothed with a median filtering technique, to reach a spectral resolution of about 20. The edges of each spectral region were cut to avoid low S/N regions at wavelength lower than about 0.90 μm and greater than about 2.2 μm. Only for 163135 we cut the spectrum at 1.65 μm, as, due to sky variability, it was not possible to properly remove the sky contribution. The obtained NIR spectra are shown in Fig. 1.

Our NIR spectra were finally combined with the visible spectra published by Fornasier et al. (2007), overlapping the common region between 0.9 and 0.95 μm. The resulting V+NIR spectra, normalized at 0.55 μm, are shown in Fig. 2. We computed the spectral slopes of all the observed objects between 1.0 and 1.6 μm (see Tab. 2). The obtained values span a small range of values, from 0.11 to 3.60 $\%/10^3$Å, with a mean value of 1.43 ± 0.41 $\%/10^3$Å.

The obtained spectral behaviors allow us to confirm the taxonomic classification published by Fornasier et al. (2007) (see Tab. 2). Our investigation in NIR wavelengths has surprisingly shown featureless spectra: we did not detect any spectral feature between 0.9 and 2.2 μm referable to the presence, on the surface of the observed bodies, of water, ices or hydrated minerals.

To model the surface composition of the observed Eurybates members we used the radiative transfer model, based on the Hapke theory, already applied to JTs by Dotto et al. (2006). We took into consideration the following materials: amorphous carbon (by Zubko et al., 1996), organic solids (e.g. kerogens by Clark et al., 1993 and Khare et al., 1991; Triton tholins by McDonald et al., 1994; titan tholins (by Khare et al., 1984) all the minerals present in the RELAB database[2], bitumen (by Moroz et al., 1998), and ices (H_2O, CH_4, CH_3OH, NH_3, and ice tholin by McDonald et al., 1996 and Khare et al., 1993). To model the surface composition of each observed object, we considered several geographical mixtures of all these compounds. For each mixture, the modeling procedure produced a synthetic spectrum, to be compared with the observed one, and calculated the geometric albedo

[2]http://www.planetary.brown.edu/relabdocs/relab_disclaimer.htm

value at 0.55 μm. A χ^2-test was applied to compare the different models tentatively considered for each target, and to select the model which better reproduces the observed spectrum. In this analysis we did not take into account the critical regions of the spectrum, around 1.4 and 1.9 μm, where telluric bands occur. We considered as best model the geographycal mixture best fitting the asteroid spectrum, and having an albedo value compatible with the typical value of C- or P-type dark asteroids and the mean value for JTs (0.041$\pm$0.002, as computed by Fernández et al., 2003). In Fig. 2 the synthetic spectra of final models (continuous lines) are superimposed on the observed spectra. Table 2 reports, for each object, the model of surface composition, as well as the computed albedo.

The obtained spectra suggest the predominance of amorphous carbon on the surface of the observed members of the Eurybates family. In particular, the spectra of 13862, 18060 and 163135 are similar to the one of pure amorphous carbon. The spectral behaviors of (3548) Eurybates, 24380 and 24420 suggest the presence on their surface of a few amount of olivine. The slightly spectral reddening of (9818) Eurymachos has been modelled using a small percentage of a reddening agent (e.g. Triton tholin).

3 Discussion and conclusions

All the spectra of Eurybates members presented in this work appear flat and featureless and confirm the taxonomic classification published by Fornasier et al. (2007). Our surface modeling has shown that the amorphous carbon seems to dominate the surface composition of the observed bodies and some

amount of silicates (olivine) could be present. The proposed models are not unique, since they depend on many parameters (e.g. physical properties of the surface, optical constants and particle size), but a complete lack of diagnostic features typical of water, ices and hydrated minerals is evident in our spectra. This result does not allow us to definitively exclude that some percentage of water ice is still present on the observed bodies, hidden by dark materials. Brunetto & Roush (2008) showed that few tens of microns of an organich-rich layer (e.g. irradiated methan ice), produced by space weathering, are enough to mask spectroscopically, in the near-infrared wavelength range, the presence of water and other volatiles below the surface.

The spectral evidences presented in this paper leave open several possibilities about the origin of the Eurybates family.

A first scenario implies the formation of the Eurybates family by the disruption of an exogenous body, i.e. coming from other Solar System regions, probably captured by Jupiter gravitational field and trapped in L_4 Lagrangian point. In this case, the origin of the parent body is a crucial point that must yet be assessed, as well as the nature and the efficiency of the capture mechanism. Of course, it is plausible that this captured parent body is not the only one in the Trojan clouds, but the population of these objects must be still assessed.

Other scenarios take into account the action of space weathering processes, still efficient at 5.2 AU from the Sun where JTs are presently orbiting (see e.g. Strazzulla et al. 2005; Melita et al. 2009). We know, from laboratory experiments, that the effect of ageing mechanisms strongly depends

on the composition and nature of the surfaces exposed to space weathering. Since we still do not know the origin and primordial composition of JTs, and therefore we do not know how space weathering processes acted on JT surfaces, several scenarios have to be considered:

a) if JTs had icy surfaces, the space weathering processes would have produced an irradiation mantle spectrally red and with low albedo (Moore et al., 1983; Thompson et al., 1987; Strazzulla, 1998; Hudson & Moore, 1999; Brunetto et al., 2006; Brunetto & Roush, 2008);

b) a similar result would have been produced on silicatic composition, where space weathering produces a gradual spectral reddening, as already observed in several dynamical families in the asteroid main belt (e.g. the Eunomia family by Lazzaro et al., 1999; the Flora clan by Florczak et al., 1998; and the Eos family by Doressoundiram et al., 1998) and shown by laboratory experiments (e.g. Strazzulla et al. 2005; Lazzarin et al. 2006);

c) an opposite result would have been produced on a surface covered of natural complex hydrocarbons, where ion irradiation would have produced gradually neutralized spectra (Moroz et al., 2004).

The first two cases bring to the possibility that the Eurybates is a young family, produced either by a the fragmentation of an object coming from outside the present Trojan population and trapped around L_4, or by a secondary collision involving one of Menelaus' family members.

Under the scenario *(c)*, Eurybates should be an old family, with an initial hydrocarbon composition, on which space weathering flattened the members' spectra, wiping out the primordial differences.

Whether JTs experienced a phase of cometary activity, water ice on their surface could have been devolatized, or they could have formed a thin dust mantle as shown by Rickman et al. (1990) and Tancredi et al. (2006). This mechanism is quite probable for large JTs not belonging to dynamical families, and it is still plausible for members of dynamical families, since we cannot exclude that they suffered some episodic cometary activity during their life after the fragmentation of the parent body. In a recent work Melita et al. (2009) estimated the timescales of the sublimation of amorphous water ice, the collisional resurfacing, and the flattening of the spectral slopes by solar irradiation in the region of JTs. According to these authors, a dust layer, probably with a red spectroscopic slope, does exist on the surface of JTs as a result of the rapid sublimation of water ice after resurfacing impact events. If this dust layer remains unaltered for more than 10^3 years, its spectroscopic slope is flattened by the action of solar protons. According to the estimated timescales, impacts are so frequent that the irradiation mantle is usually disrupted for JTs, but in the case of the Eurybates family the flat spectra would suggest that we are seeing aged surfaces.

The knowledge of the age of the Eurybates family is hence fundamental for understanding the parent body origin and nature. More observations are also absolutely needed to see whether this peculiar family is unique or if more Eurybates-like families are present in both L_4 and L_5 swarms.

At the same time more observations of Menelaus objects are needed to compare Eurybates and Menelaus members with the whole population of JTs, to have more hints on the relation between Eurybates family and Menelaus

clan, and to cast some light on their (common or not) origin.

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TABLES and FIGURES

Table 1: Observational circumstances. For each object, we report observing date, exposure time, airmass and solar analog used (with correspondent airmass).

Object	Date	T_{exp} ($s\times$ n_{acq})	Airmass	Solar Analog (airmass)
3548 Eurybates	18 Aug 2006	120 x 8	1.8	Hip102491 (1.9)
13862	15 Jul 2007	120 x 16	1.6	HD210078 (1.4)
18060	16 Jul 2007	120 x 16	1.3	HD210078 (1.3)
9818 Eurymachos	17 Jul 2007	120 x 24	1.7	HD210078 (1.4)
24380	17 Jul 2007	120 x 16	1.4	HD210078 (1.3)
24420	04 Aug 2007	120 x 16	1.5	HD210078 (1.3)
163135	04 Aug 2007	120 x 32	1.5-1.8	HD210078 (1.3)

Table 2: For each object, the spectral slope S_{NIR} (computed between 1.0 and 1.6 μm), taxonomic classification given by Fornasier et al. (2007), the model of the surface composition and computed albedo value at 0.55 μm are reported. The used acronyms are: AC = amorphous carbon, Tr. th. = Triton tholin, Ol = olivine.

Object	S_{NIR} (%/10^3Å)	Tax. class	Model	Albedo
3548 Eurybates	1.82 ± 0.41	C	99% AC – 1% Ol	0.03
13862	0.11 ± 0.31	C	100% AC	0.03
18060	1.11 ± 0.27	P	100% AC	0.03
9818 Eurymachos	3.60 ± 0.38	P	98% AC – 2% Tr. th.	0.03
24380	0.98 ± 0.55	C	99% AC – 1% Ol	0.03
24420	2.12 ± 0.50	C	99% AC – 1% Ol	0.03
163135	0.25 ± 0.55	P	100% AC	0.03

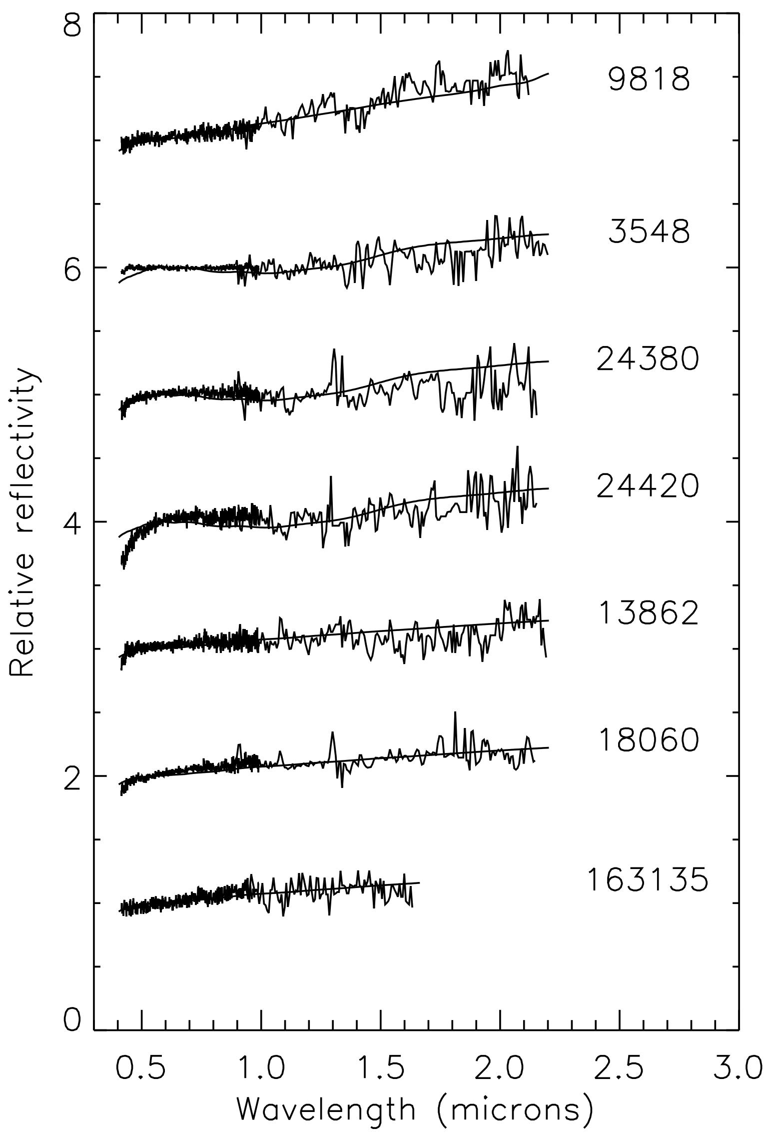

Figure 1: Near-infrared spectra of Jupiter Trojans belonging to Eurybates family. All the spectra are normalized at 1.25 μm and shifted by 1.0 in reflectance for clarity. Their mean S/N ratio value, measured at about 1.25 μm, is around 15.

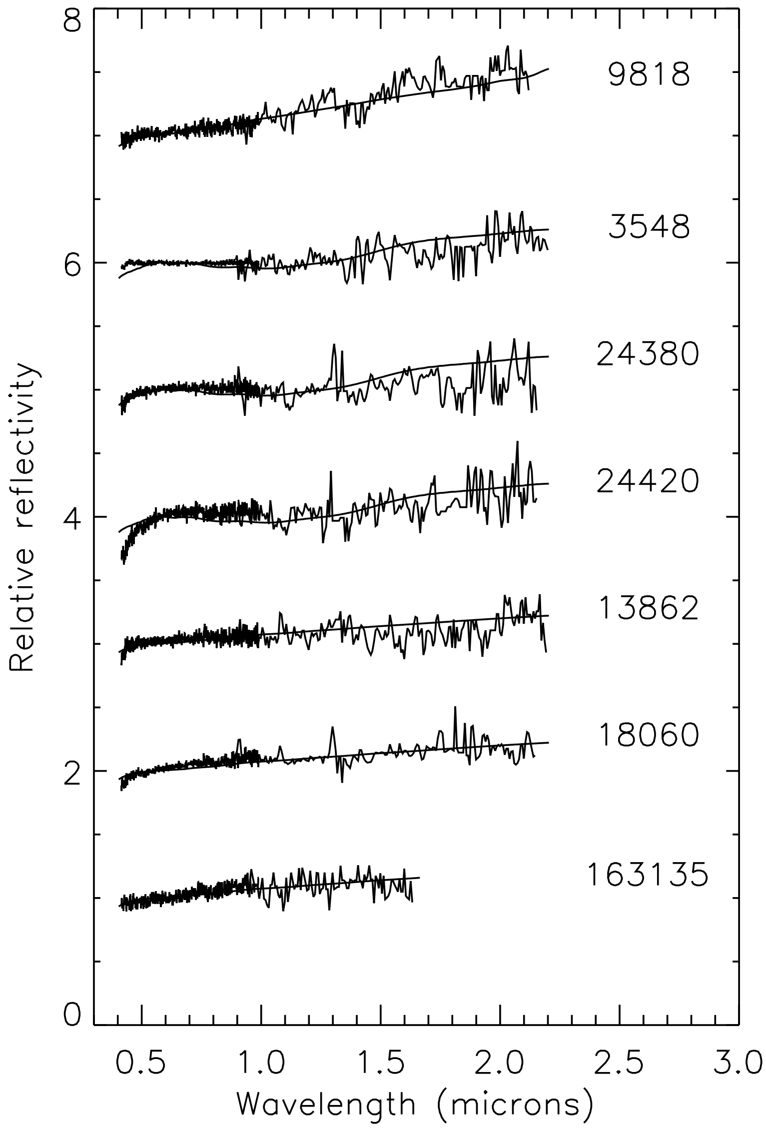

Figure 2: Near-infrared spectra of Eurybates family members obtained by our observations, together with the visible part already published by Fornasier et al. (2007). All the spectra are normalized at 0.55 μm and shifted by 1 in reflectance for clarity. The superimposed continuous lines represent the synthetic spectra obtained modeling the surface composition.